NASA TECHNICAL TRANSLATION NASA TT F-17441

RETENTION OF SELECTED PHYSIOLOGICAL INDICATORS IN PILOTS IN THE COURSE OF AGRICULTURAL FLIGHTS

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(NASA-TT-F-17441) RETENTION OF SELECTED PHYSIOLOGICAL INDICATORS IN PILOTS IN THE COURSE OF AGRICULTURAL FLIGHTS (Scientific Translation Service) 14 p HC A02/MF A01 CSCL 06S G3/52

N77-33845

Unclas
49438

Translation of "Zachowanie sie wybranych wskaznikow fizjologicznych u pilotow podpczas lotow agrotechnicznych", Ergonomics in Aviation; National Scientific-Technical Conference, 1st, Warsaw, Poland, Mar. 17-19, 1975. Proceedings. pp. 41-52

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 AUGUST 1977

STANDARD TITLE PAGE

1. Report No. NASA TT F-17441	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle RETENTION OF SELECTED PHYSIOLOGICAL INDICATORS IN PILOTS IN THE COURSE OF AGRICULTURAL FLIGHTS		5. Report Date August 1977 6. Performing Organization Code
7. Author(s) Lech Markiewicz, Danuta Koradecka and Maria Konarska		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2791 13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Zachowanie sie wybranych wskaznikow fizjologicznych u pilotow podpczas lotow agrotechicznych", Ergonomics in Aviation; National Scientific-Technological Conference, 1st, Warsaw, Poland, Mar. 17-19, 1975. Proceedings. pp. 41-52 (A76-28530)

16. Abstract

Stress on the organism of pilots maneuvering fixed-wing or rotary-wing aircraft in crop-dusting and sowing operations, with abrupt changes in terrain and sharp turns required, is studied on the basis of telemetered heart rate, tremorgrams, indications of muscle fatigue (particularly, flexor muscles of the fingers), and response to vibrations. Comparisons are made of data for low-level flight over even terrain and nap-of-the-earth flight over hilly terrain. Responses in fixed-wing flight and helicopter flight are also contrasted. Criteria are proposed for optimization of piloting conditions in this type of service. Restrictions on interpretation of the data are stated, and data are presented in tabular and graphic form.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22.

RETENTION OF SELECTED PHYSIOLOGICAL INDICATORS IN PILOTS IN THE COURSE OF AGRICULTURAL FLIGHTS

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ABSTRACT. This research was an attempt to evaluate the strenuousness of the work of the pilot while making agricultural flights on PZL-101 and AN-2 airplanes and on SM-1 and MI-2 helicopters. Our research was also an attempt to apply various physiological methods to an analysis and evaluation of pilot stress during work. Research was carried out on heart beat frequency by a telemetric method before flights and during individual flight phases; research on the strenth and stamina of the flexor muscles of the fingers, tremographic research, and indications of feelings of vibration were carried out before and after flights.

During individual flight phases, a considerable increase in heart beat rate was found, indicating great emotional and physical stress, especially at the time of takeoff and landing, and reduction in muscle strength and stamina after flight. Results of the tremographic research and determination of feeling of vibration are not clear.

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The work of the pilot in agricultural service is characterized /41* by a high degree of difficulty. Specific of this type of work is flight at so-called 0 altitude (from 0.5 to several meters above the ground) and the need to make frequent turns. Performing this type of work requires the greatest skill in piloting, associated with a need for constant alertness. Depending on climatic conditions, the type of equipment and the type of service, several to dozens of flights are made in the course of a day. Flight duration varies from several minutes to hours. The chance of correcting an error in this type of flight is minimal, and every mistake can end in an accident.

In this situation an analysis of the development of fatigue during the work of the pilot in agricultural service is particularly essential. We have subjected the work of a pilot in agricultural services with equipment of various types, on the PZL-101 "Gawron /42 [Rook]"and AN-2 airplanes and on the MI-2 and SM-2 helicopters, to such an analysis. The research was carried out under various types of working conditions, on lowland and piedmont terrain and in various seasons of the year, spring and fall. Such a schedule of research was justified by the use of various kinds of equipment and a variety of services (fertilizing, dusting, etc.) in agricultural work.

Among the physiological indicators we examined were the heart beat frequency on the basis of EKG recordings (by line or telemetric method), indicators of strength and stamina of the flexor muscles of the fingers and the extensors of the spine with the aid of an electrodynamometer, time spent on a mission and the number of mistakes in a tremographic test, and threshold values and feeling vibrations with the aid of a MCW-2 gauge. Five pilots with a great deal of experience in "agro" flights were subjected to the examinations. The research was carried out both during natural operations and in simulated programs, worked out on the basis of data from the Institute of Aviation as typical of conditions for these flights.

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*Numbers in the margin indicate pagination in the original foreign text.

We used a research pattern taking into consideration measurements under conditions of rest, before starting, during direct flight, during turns, and during landing. Along with the research on physiological indicators, there were parallel psychological tests which will be the subject of a separate paper.

1. Results of comparative examinations of stress during "agro" flights on the PZL-101 and AN-2 airplane

Heart beat rate, an indicator of physical and emotional stress during flight, increased more during flights with the PZL-101, reaching 150% of rest values, to 130% for flights in the AN-2. The most stressful periods while piloting the PZL-101 can be designated, in turn, as factors associated with landing, flights over an obstacle, and turning (Table 1, Figure 1). On the other hand, the highest values were recorded on the AN-2 during factors associated with flight over an obstacle, take-off, and turning.

The increase in the heart beat rate recorded before take-off, in comparison with the frequency recorded at rest, is testimony of the role of emotional stress. This increase amounted to 114% of the values determined at rest for pilots using the PZL-101 airplane, and 131% for those on the AN-2.

Data from interviews, measurements of heart beat frequency, /43
research on indicators of strength and stamina of muscles and the results of psychological tests agree in attributing considerable physical stress to making these flights.

The frequency of heart beats, reaching 145 per minute, would agree with the accepted criteria for defining the work of an "agro" pilot as rather difficult physical labor. However, we must not forget to add the components of emotional stress here. The values of physiological indicators established indicate the constant nature of the stress, since the flights require turns every 30, and sometimes even every 8 seconds. Each turn requires considerable

physical effort associated with overcoming the resistance of the controls, as well as the trim tab on the PZL-10.

The marked drop in the stamina of the muscles of the upper extremities, to 30% of their rest value after flights in the PZL-101 and to 70% of their rest value after flights in the AN-2 (Table 3, Table 4, Figure 3), verifies this condition of stress. We also find a definite extension of the time for performing tests after a series of flights in our tremographic examinations.

2. Results of comparative analysis of pilot stress during agricultural flights over lowland terrain and over piedmont terrain

The work of the pilot over piedmont terrain is characterized by a higher degree of difficulty in piloting. The features of the terrain make it more difficult to select suitable landing areas, which for this reason usually have a runway shorter than optimal. Also specific for mountainous conditions are thermal conditions producing phenomena of air masses sliding and revolving on slopes. This requires anticipation of thermal conditions as a function of terrain features. Here good visibility is necessary, something which is particularly difficult in the case of piloting the PZL-101. These exceptionally difficult piloting conditions were the cause of considerable stress found in examining a pilot making "agro" flights in piedmont territory.

In comparision with 72 beats per minute at rest, the heart beat frequency increases with particular intensity during landing (up to 147% of rest values, Table 2, Figure 2). The value of this indicator was constant during successive flights (from V to XXV), which can be explained by maximum mobilization of the organism under these difficult conditions. On the other hand, while carrying out activities with a strength stress nature, such as turns and sowing chemical agents, an increase was observed in heart beat frequency up to 137% of rest value, with the appearance of an increase in organism stress in successive flights. At the same time, in

successive flights there was a reduction in emotional stress associated with starting, and from an increment amounting to 117% of rest value after flight V, it diminished to 108% after flight XV, and 105% after XXV. This may be attributed to a certain degree of adaptation to starting conditions. /44

3. Results of comparative analysis of pilot stress during agricultural flights in an airplane and in a helicopter

In comparison with airplanes, the helicopter appears to have a number of essential virtues in agricultural service, among others facility in takeoff and landing, and fewer requirements in regard to meteorological conditions. Until now there has been a complete lack of information on the subject of stress on the organism of a helicopter pilot while making "agro" flights.

The working time of the helicopter pilot amounts to about 5 hours daily, obviously as a function of meteorological conditions. A single flight lasts about 10 minutes and is limited by the volume of containers with chemicals. A helicopter cabin assures good field visibility. The strength required to operate the steering equipment is not very great either (especially in the case of the MI-2).

The highest heart rate values were recorded on the SM-1 during such activities as turning and flying over a field. On the other hand, lower heart beat frequency values were recorded during takeoff and landing. After finishing a series of flights, the values indicating the strength of the flexor muscles of the fingers decreased by 5%, and the stamina indicators by 15%. The threshold values of feeling vibrations increased in the range of the complete spectrum by about 5 dB and a little higher, since they were about 10 dB in the frequency range of 400, 500, and 640 Hz.

The highest heart rate values on the MI-2 were determined during turns and landing (about 140/min) during the first flights, while this indicator reached lower levels (about 115 beats/min)

during successive flights of a series. The strength indicating values diminished to 87 - 90%, and the stamina indicator to 74 - 84% of rest values. The threshold values of feeling vibrations increased negligibly in both pilots examined in the low frequency area, and simply dropped (from 3 to 17 dB) in the high frequency range. It seems that such a shift in the threshold of feeling vibrations can be associated with numbness from the movements of the hands, but measurements of the spectrum of stick vibrations are necessary for a complete interpretation. /45

All of the research results presented should be interpreted with a great deal of caution in view of the following facts:

- the small number of pilots available for investigation,
- the variability in the experimental conditions (time of year, length of individual flights and of series of flights, simulation of working activities), and
- varied intensity of flights before the experiment.

Here we should stress the interesting phenomenon of worse parameters of physiopsychic activity in pilots facing a series of spring flights in comparison with a series of autumn flights. This is borne out by higher EKG rest values, longer reaction times, and a higher threshold of feeling vibrations. It is possible that these differences are the result of seasonal rhythms of efficiency.

In analyzing the causes of so-called pilot organism stress during "agro" services, it is necessary to mention:

1) the physical effort associated with using steering and control equipment,
2) the uncomfortable position,
3) considerable emotional stress, and
4) the arduous conditions of the working environment (microclimate, noise, vibrations, chemical factors).

In connection with the above, optimization of pilot working conditions could proceed in the direction of:

1) reducing the resistance of the stick, rudder, gas, chemical release and trimming tab for the PLZ-101;

2) consideration during designing the working space of the specific structures of pilot activity during "agro" services (moving the gas pedal and helicopter pitch devices closer, moving the stick, placing the chemical release on the stick, and having the chemical drop on the PZL-101 along side of the throttle;

3) improving the body position (regulation of the height and depth of the seat, regulation of the pedals in two planes); /46

4) guaranteeing precision of action(graduations on the throttle, proper lining and hood on the pedals);

5) improvement in the cabin microclimate conditions (assurance against cabin overheating, air conditioning, handle on drinking container);

6) reducing the level of noise and vibration;

7) protection against exposure to the action of chemical factors (loading from the side of the airplane, sealing off the load in the cabin), and

8) guaranteeing suitable rest conditions during breaks and after work.

Analysis of fatigue factors during "agro" flights seems to lead to the conclusion that the maximum time for safe stressing of the organism by flight is a period of 3 hours. After this time, we observe a considerable drop in the psychophysiological efficiency of the organism.

The stress on the pilot organism during "agro" flights on helicopters seems to be less than the stress associated with airplane flights.

Since situations of extreme stress, typical of working conditions, and natural in particular arduous, microclimatic conditions and over difficult terrain, seem to be decisive in the psychophysical stress of the pilot, it seems expedient to carry out comparative research by using a methodology applicable to such experimentally difficult situations.

Without negating the role of the above terrain research, at the present time we consider it expedient to carry out a series of experimental investigations on the model environment of the pilot's cabin.

TABLE 1. FREQUENCY VALUES OF HEAT BEATS OF PILOTS DURING AGRICULTURAL FLIGHTS IN VARIOUS TYPES OF AIRCRAFT AND HELICOPTERS /47

Type	At rest		Before start		Start		Direct flight		Flight over obstacle		Turns		Landing		After landing	
		Change in %		Change in %		Change in %		Change in %		Change in %		Change in %		Change in %		Change in %
	73	100	83	114	96	131	100	137	120	164	96	131	125	171	103	140
	75	100	98	131	110	147	96	128	115	155	108	144	104	140	98	131
	66	100	83	126	81	123	87	132			92	139	78	118		
	72	100	84	117	99	137	106	147			106	147	101	140		
Arithmetic mean	71		87		96		97		117		100		102		103	

TABLE 2. COMPARISON OF FREQUENCY OF HEAT BEATS DURING AGRICULTURAL PILOTING ON A PLZ-101 AIRPLANE IN PIEDMONT AND LOWLAND TERRAIN /48

Terrain	Flight phases									
	At rest		Before start		Start		Turns		Landing	
		Change in %		Change in %		Change in %		Change in %		Change in %
Lowland	73	100	83	114	96	131	96	131	125	171
Piedmont	78	100	86	110	108	138	106	136	115	147

TABLE 3. CHANGES IN THE FLEXOR MUSCLE STRENGTH IN FINGERS AFTER AGRICULTURAL FLIGHTS ON VARIOUS TYPES OF AIRPLANE AND HELICOPTERS

Type	Flexor muscle strength of fingers of hand in kg					
	Left			Right		
	Before flight	After flight	Change in %	Before flight	After flight	Change in %
PZL - 101	52	47	90	50	54	108
AN - 2	55	55	100	55	55	100
SM - 1	44	42	95	46	47	102
MI - 2	60	52	87	62	56	90

TABLE 4. CHANGES IN STAMINA OF FLEXOR MUSCLES OF FINGERS AFTER AGRICULATURAL FLIGHTS ON VARIOUS TYPES OF AIRPLANES AND HELICOPTERS

	Stamina of flexor muscles of fingers of hand in seconds					
	Left			Right		
	Before flight	After flight	Change in %	Before flight	After flight	Change in %
PZL - 101	41	25	61	57	21	37
AN - 2	29	25	86	31	23	74
SM - 1	40	34	85	34	40	118
MI - 2	98	72	74	139	117	84

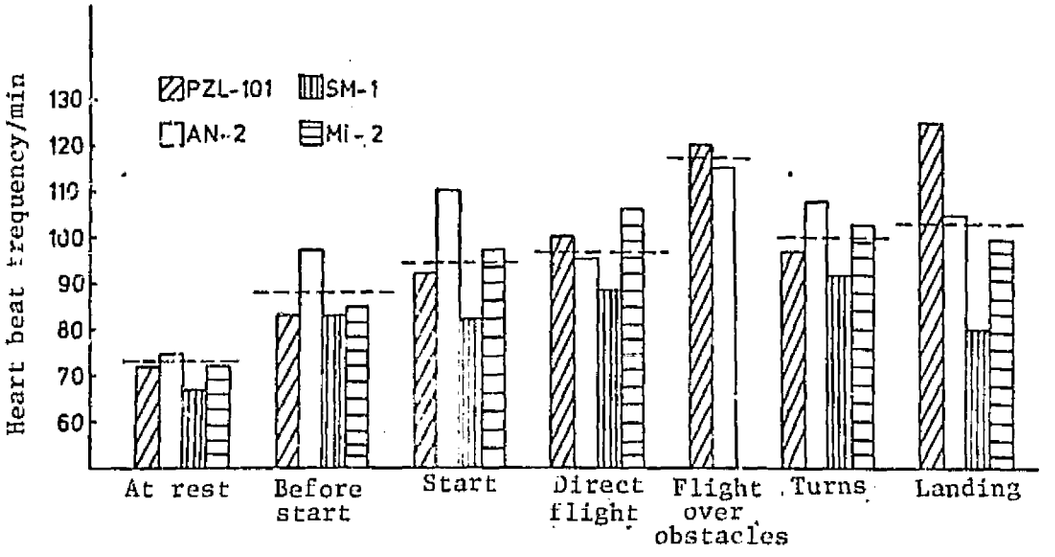

Figure 1. Changes in frequency of heart beat of pilots during agricultural flights on various types of airplanes and helicopters

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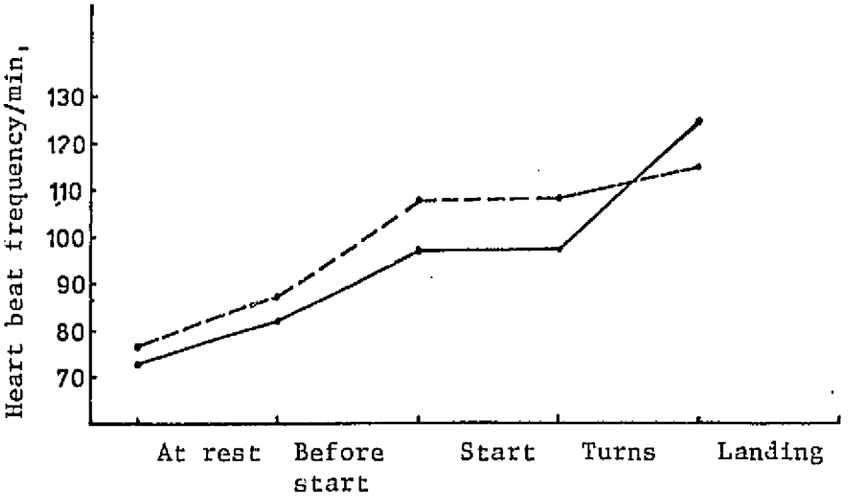

Figure 2. Comparison of heat beat frequency during agricultural piloting of the PZL-101 airplane in Piedmont (-----) and lowland (———) terrain

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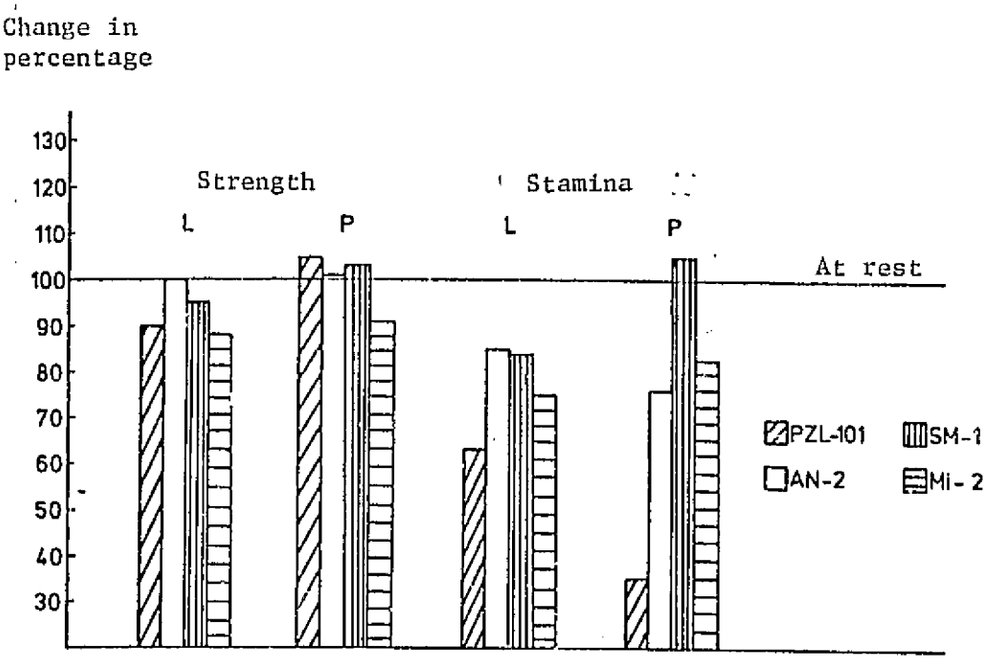

Figure 3. Changes in strength and stamina of flexor muscles of fingers after agricultural flights on various types of airplanes and helicopters